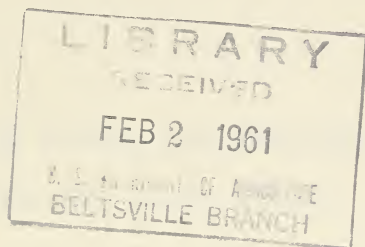


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AGRICULTURAL DROUGHT
and
EXCESS SOIL MOISTURE
in Eastern North Dakota
and South Dakota

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Agricultural Research Service

UNITED STATES DEPARTMENT OF AGRICULTURE

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Agricultural Drought and Excess Soil Moisture in Eastern North Dakota and South Dakota

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Successful crop production requires an adequate supply of soil moisture throughout the growing season. Even on well-drained soils an erratic precipitation pattern and intensity often cause a reduction of the available moisture supply as well as an excess of moisture. Recent advances in agronomic practices in the United States point out the need for more water and for information on the reliability of our natural water supply. The occurrence and frequency of soil-moisture deficits and excesses are important in determining the agricultural needs for water in North Dakota and South Dakota.

AGRICULTURAL DROUGHT

Agricultural drought may be defined as a condition in which there is insufficient moisture available in the root zone for plant growth and development. When this condition exists for 1 day, it is called a drought-day.

Agricultural drought is dependent not only on the precipitation pattern but also on the evapotranspiration, the soil-moisture storage capacity, and the moisture requirements of plants. It is not the purpose here to establish what the effects of these factors are on the soil-moisture balance, for there is no general agreement on their relationship, but to show that agricultural drought and excess soil moisture can be predicted under specified conditions of soil-moisture availability, evapotranspiration, and precipitation provided sufficient data are given.

PROCEDURES

The procedures used here were first described by Van Bavel in 1953 (4)² and later used in a study of drought in North Carolina reported in 1956 (8). In the latter publication the procedures and complica-

¹ The author is indebted to C. H. M. van Bavel, who first developed the present method of estimating drought and who supervised much of this study, and to the National Weather Records Center of the U.S. Weather Bureau at Asheville, N.C., which collected the precipitation data and did the machine computations on which this report is based.

² Italic numbers in parentheses refer to Literature Cited, p. 30.

tions arising from the basic assumptions are discussed to some length. In later studies (5,6,7) these same procedures were used.

For this study 10 stations were selected in North Dakota and 13 in South Dakota east of the 100th meridian where daily precipitation records were essentially complete from 1932 through 1956. These stations are shown in figure 1.

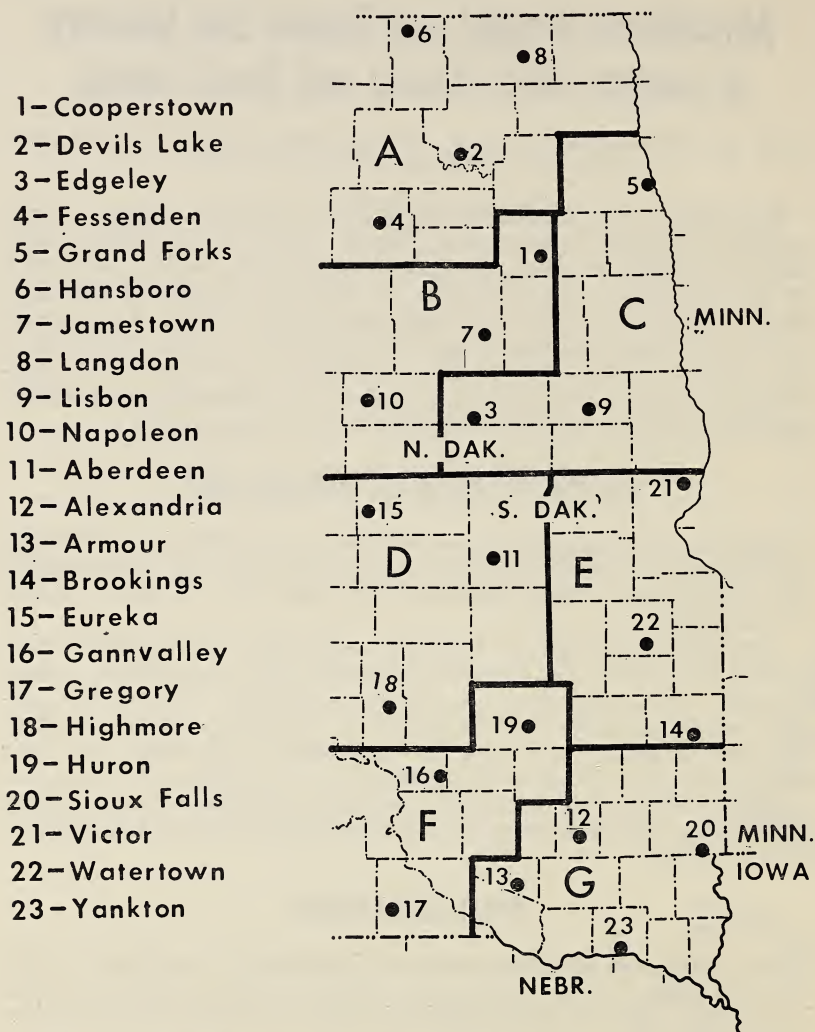


FIGURE 1.—Map of eastern North Dakota and South Dakota showing 23 precipitation stations and 7 areas (A-G) used for monthly drought probabilities.

Three stations were also selected in North Dakota and one in South Dakota, where climatological data were recorded for estimating daily evapotranspiration by the Penman formula (1, 2, 3). Daily values

may deviate considerably from monthly averages, but in the calculation procedure the effect of daily variations is largely eliminated. The average monthly precipitation versus the average monthly evapotranspiration is shown in figure 2 for these stations. On the basis

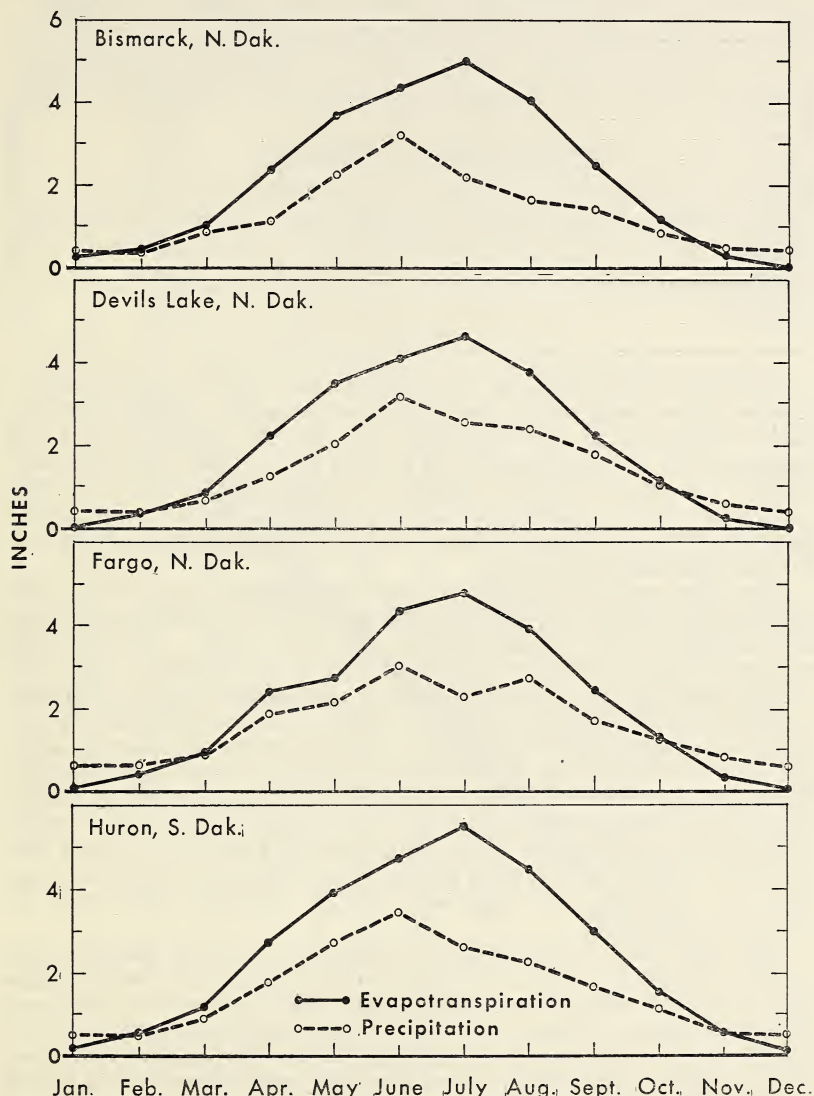


FIGURE 2.—Average monthly precipitation and evapotranspiration at three stations in North Dakota and one station in South Dakota.

of these values it was decided to treat North Dakota and South Dakota as separate evapotranspiration areas. The values used are shown in table 1.

TABLE 1.—*Estimated daily maximum evapotranspiration in eastern North Dakota and South Dakota for each month*

Month	North Dakota	South Dakota
	<i>Inches per day</i>	<i>Inches per day</i>
January.....	0. 00	0. 01
February.....	. 02	. 02
March.....	. 03	. 04
April.....	. 08	. 09
May.....	. 12	. 12
June.....	. 15	. 16
July.....	. 16	. 17
August.....	. 13	. 14
September.....	. 09	. 10
October.....	. 04	. 05
November.....	. 01	. 02
December.....	. 00	. 01

In order to compute the daily balance of available soil moisture, the storage capacity of the root zone must be known. This depends on such variables as the field capacity of the soil, the depth of the rooting zone, and the moisture content of the soil at the lower limit of availability. Because of these conditions different soil-moisture storage capacities must be considered. In this study soil-moisture storage capacities of 1, 3, 5, 7, and 9 inches were used as parameters and are referred to as base amounts.

Since the period from May through September is the one of most agricultural activity, the estimates of agricultural drought and excess soil moisture were confined to this 5-month period. However, the moisture balance was figured on a daily basis from 1932 through 1956.

In estimating the moisture balance, it was assumed that on January 1, 1932, the soil moisture was at a maximum value. Thereafter a new balance was computed each day by adding any precipitation that occurred and subtracting the estimated amount of evapotranspiration. However, two restrictions were placed on the moisture values. If at any time the moisture exceeded the base amount, the amount of excess was recorded, and the next day's balance started with the original base amount. Also, if at any time the moisture balance reached zero, that day was considered a drought-day, and no negative values were allowed to accumulate.

Because of the extremely large number of data and computations, IBM machines and cards were used to catalog the data and to make the necessary calculations. This work was done at the National Weather Records Center. The daily precipitation data for each of the 23 stations were punched on cards. A working deck of cards was then prepared consisting of one card for each day of the 5-month period. The evapotranspiration values were punched on each card and the daily balance for each of the five base amounts was computed. The occurrence of either a drought-day or an excess amount of moisture was noted on the card. The tabulations showed the total number of drought-days and excess amounts for each station, each base amount, each year, and each month, as well as the total for the

5-month period. The tabulated data were then analyzed and interpreted.

DISCUSSION

In figure 2 the average monthly evapotranspiration exceeds the average monthly precipitation from March through October, which includes the period studied from May through September. It is obvious that drought may occur during this period. However, this is only a qualitative evaluation of the situation.

Seasonal Drought-Days

A frequency distribution was prepared of the total number of drought-days during the season from May through September for each of the 23 stations. Figures 3-9 are examples of these frequency

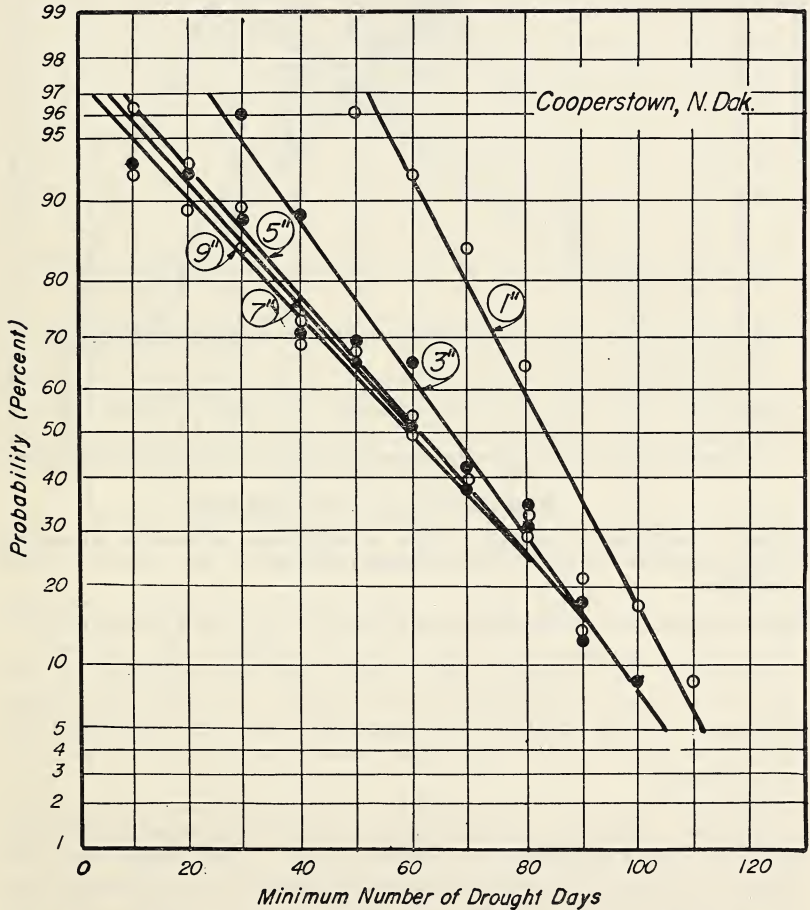


FIGURE 3.—Probability for minimum number of drought-days to occur for soil-moisture storage capacities of 1, 3, 5, 7, and 9 inches at Cooperstown, N. Dak., from May through September.

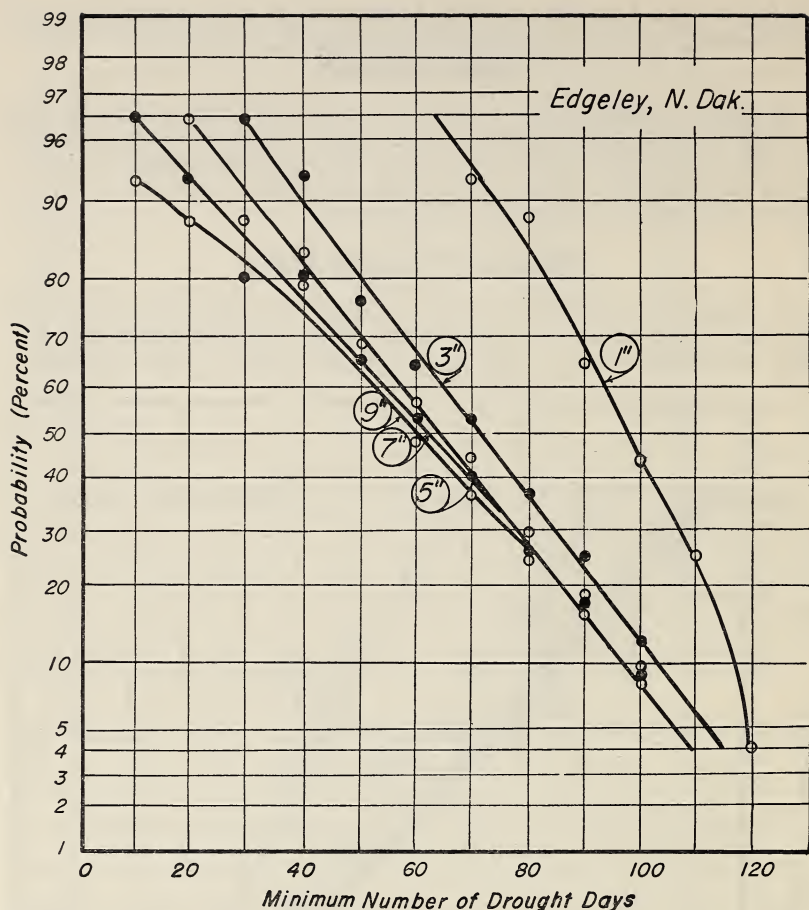


FIGURE 4.—Probability for minimum number of drought-days to occur for soil-moisture storage capacities of 1, 3, 5, 7, and 9 inches at Edgeley, N. Dak., from May through September.

distributions for each base amount and are typical of the stations in each of the seven areas of similar drought incidence (fig. 1).

As seen in these graphs, some of the frequency distributions did not have a linear relationship when plotted on probability paper. Differences in the number of drought-days were not very great for soils of 5-, and 7-, and 9-inch base amounts, especially at the lower probabilities.

Figures 3-9 are not very useful in comparing different areas of the two States. However, the information on the total seasonal drought-days has been summarized in figures 10-14. These maps show the minimum number of drought-days to be expected for five base amounts at four probabilities, namely 1, 2, 3, and 5 out of 10 years. For example, in figure 12 for a 5-inch base amount at a probability of 1 out of 10 years, at least 100 drought-days may be expected in the

western area of eastern North Dakota and South Dakota and less than 80 drought-days in the eastern area.

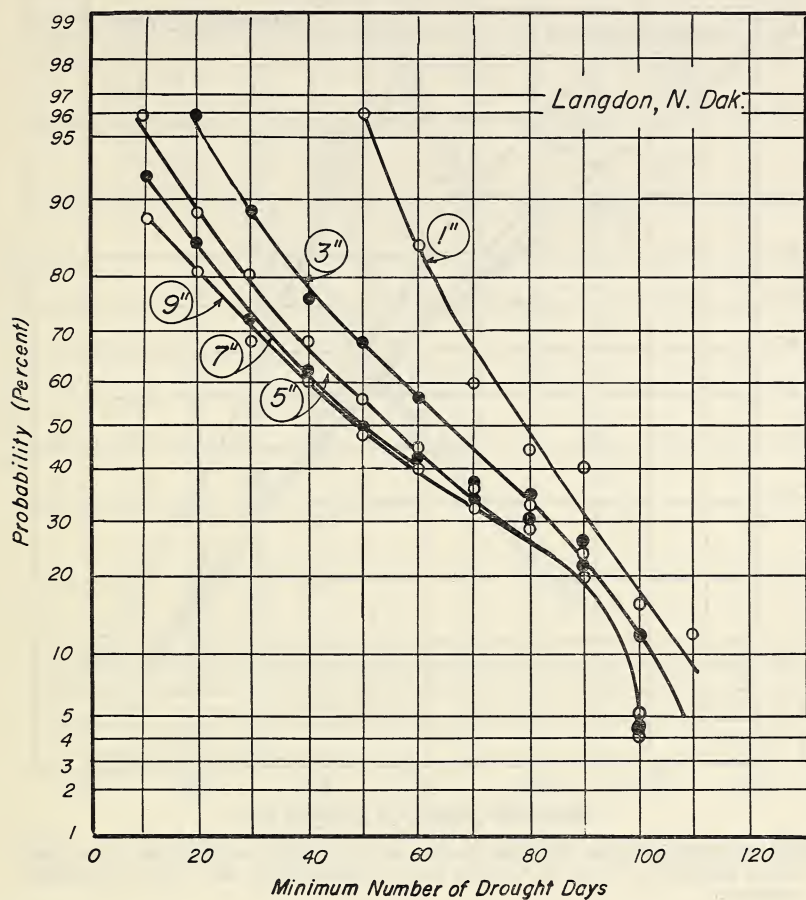


FIGURE 5.—Probability for minimum number of drought-days to occur for soil-moisture storage capacities of 1, 3, 5, 7, and 9 inches at Langdon, N. Dak., from May through September.

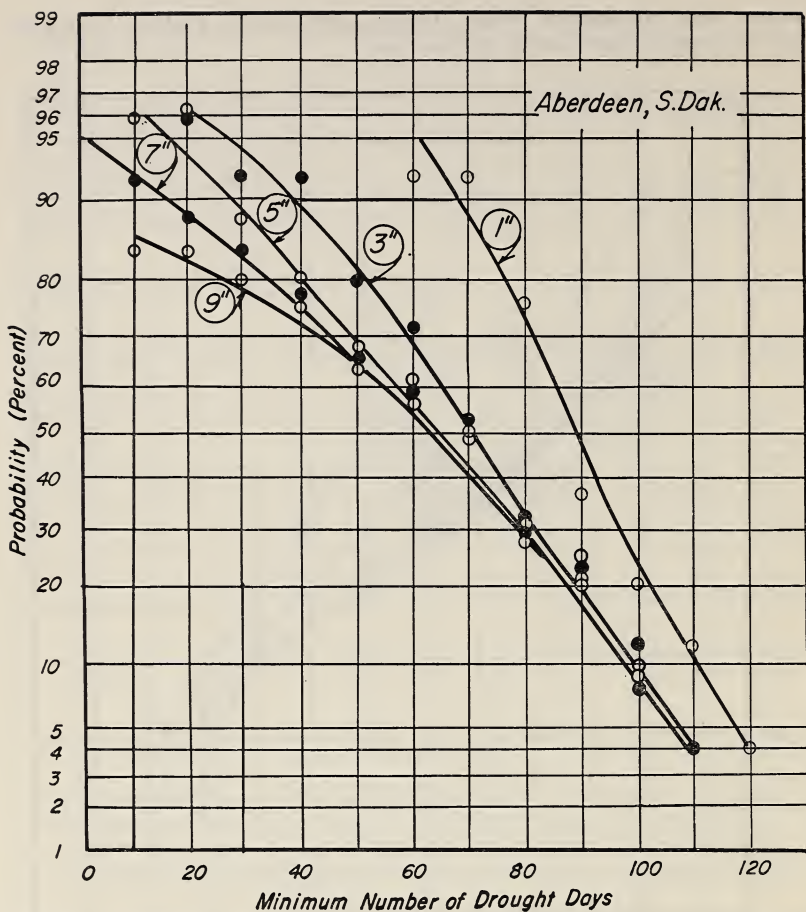


FIGURE 6.—Probability for minimum number of drought-days to occur for soil-moisture storage capacities of 1, 3, 5, 7, and 9 inches at Aberdeen, S. Dak., from May through September.

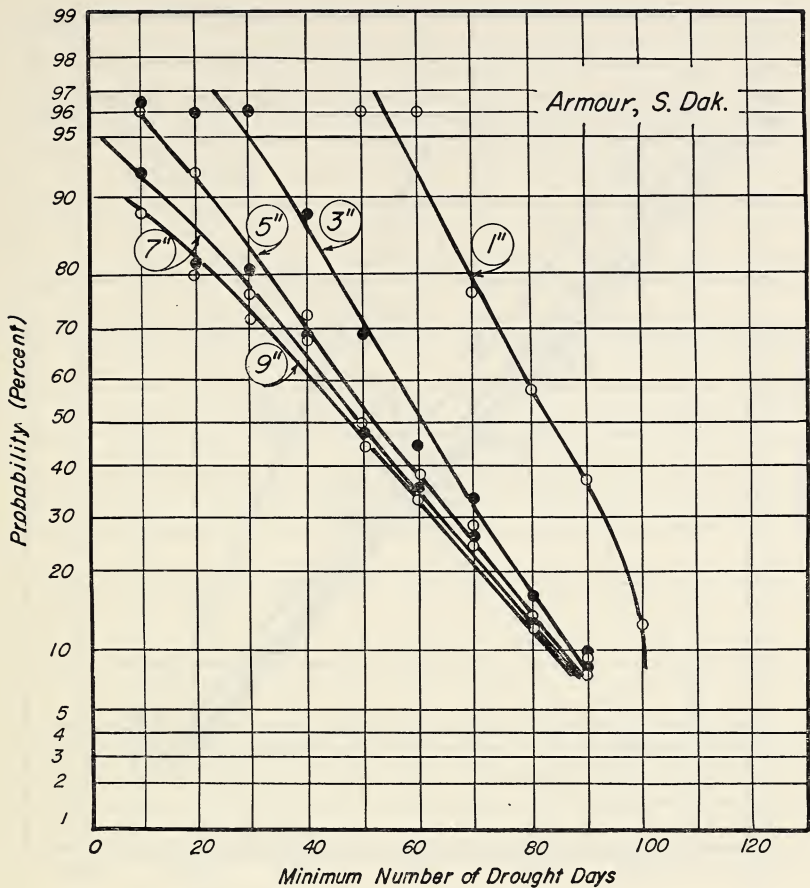


FIGURE 7.—Probability for minimum number of drought-days to occur for soil-moisture storage capacities of 1, 3, 5, 7, and 9 inches at Armour, S. Dak., from May through September.

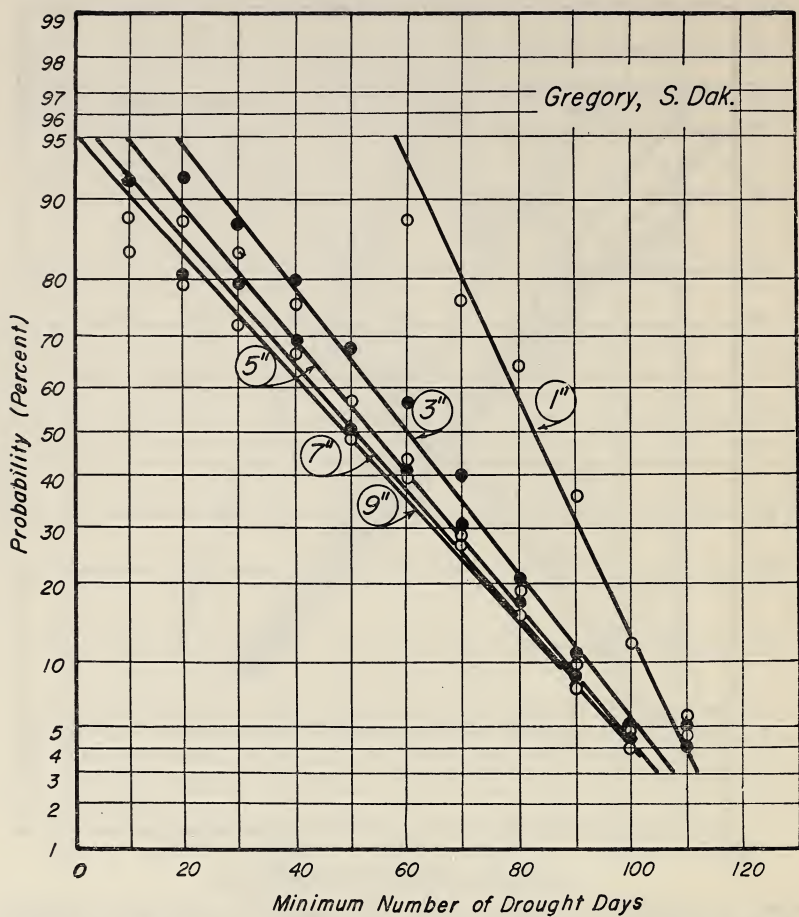


FIGURE 8.—Probability for minimum number of drought-days to occur for soil-moisture storage capacities of 1, 3, 5, 7, and 9 inches at Gregory, S. Dak., from May through September.

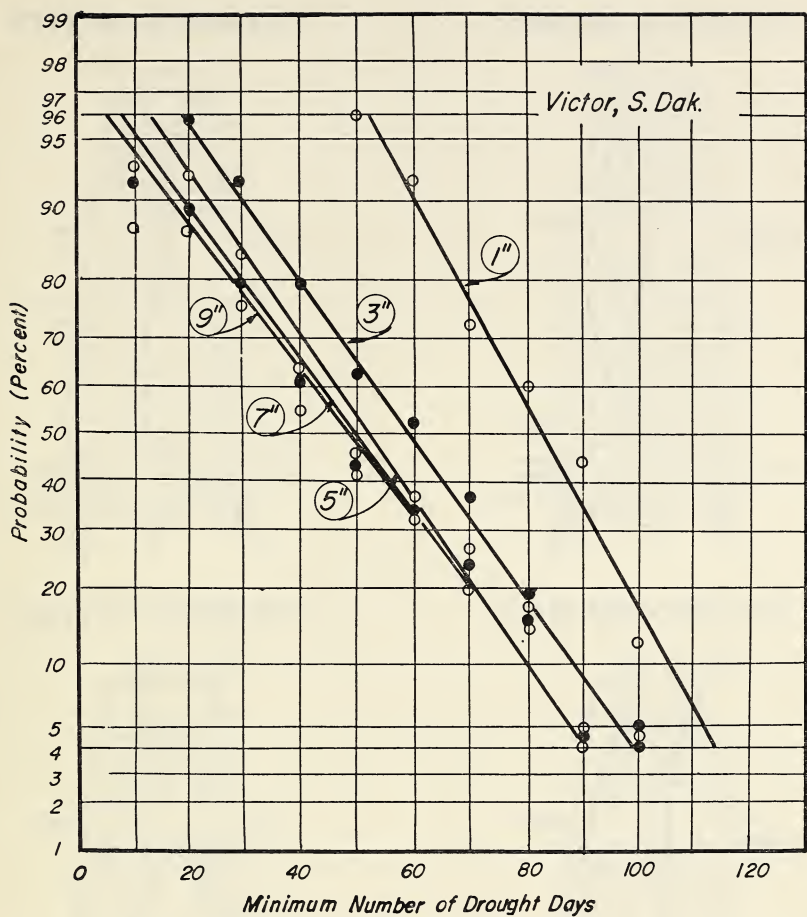
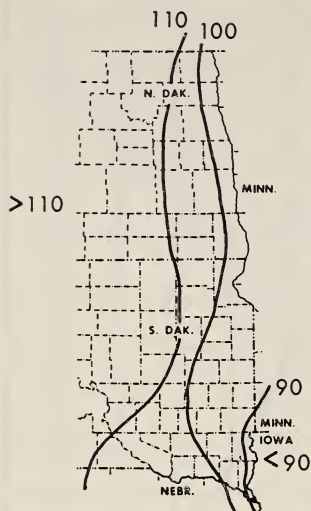
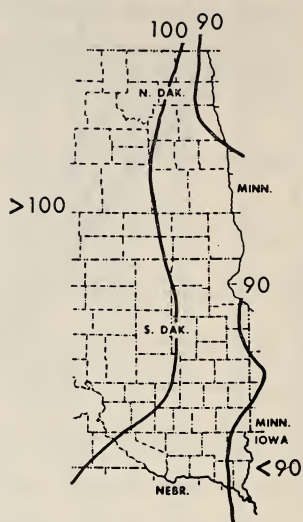


FIGURE 9.—Probability for minimum number of drought days to occur for soil-moisture storage capacities of 1, 3, 5, 7, and 9 inches at Victor, S. Dak., from May through September.

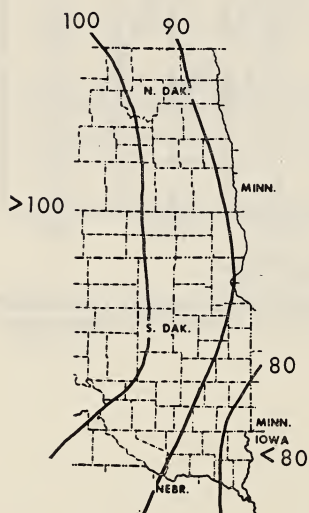
1 OUT OF 10 YEARS



2 OUT OF 10 YEARS



3 OUT OF 10 YEARS



5 OUT OF 10 YEARS

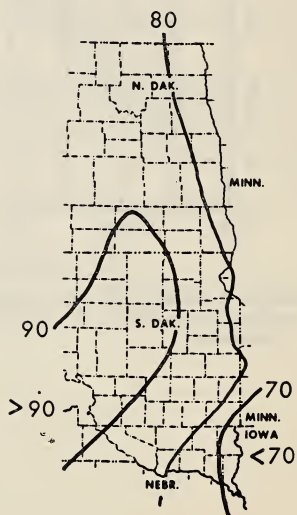
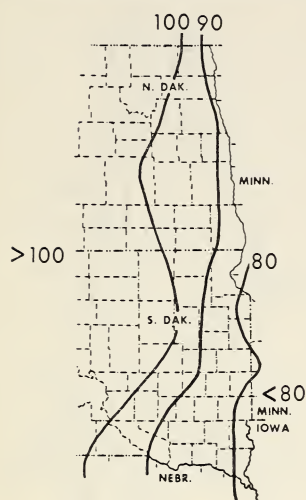
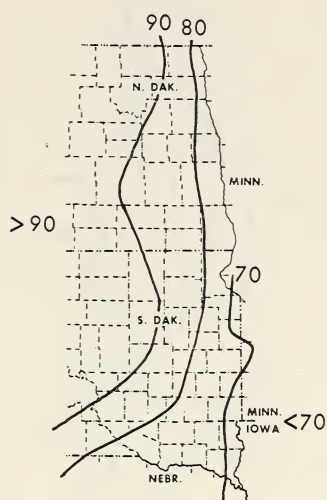


FIGURE 10.—Minimum number of drought-days to be expected for 1-inch base amount of soil-moisture storage capacity at probabilities of 1, 2, 3, and 5 out of 10 years in eastern North Dakota and South Dakota from May through September.

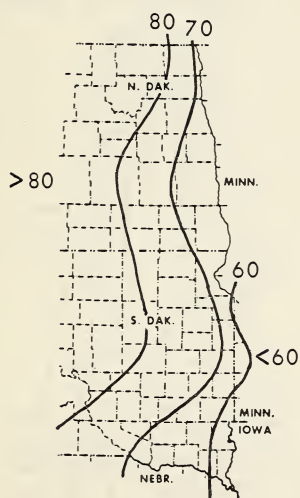
1 OUT OF 10 YEARS



2 OUT OF 10 YEARS



3 OUT OF 10 YEARS



5 OUT OF 10 YEARS

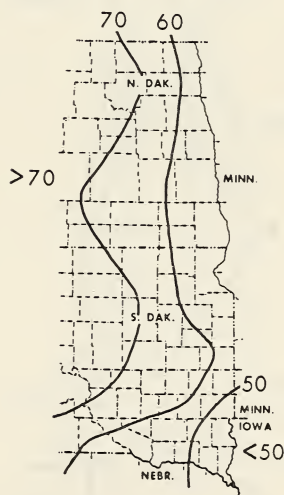
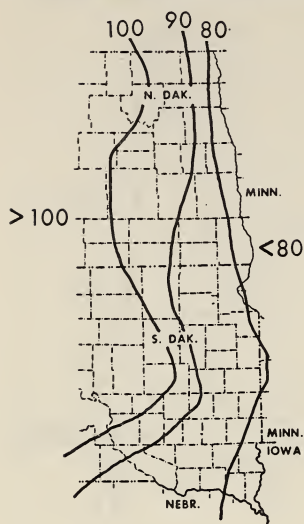
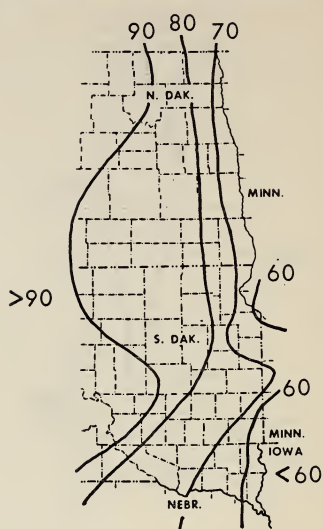


FIGURE 11.—Minimum number of drought-days to be expected for 3-inch base amount of soil-moisture storage capacity at probabilities of 1, 2, 3, and 5 out of 10 years in eastern North Dakota and South Dakota from May through September.

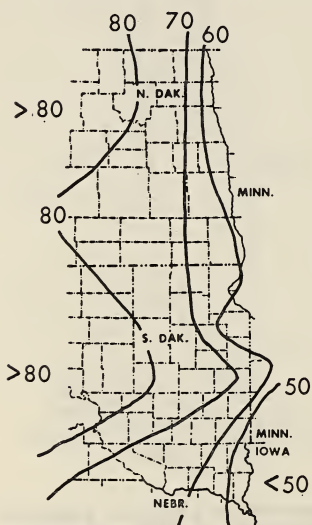
1 OUT OF 10 YEARS



2 OUT OF 10 YEARS



3 OUT OF 10 YEARS



5 OUT OF 10 YEARS

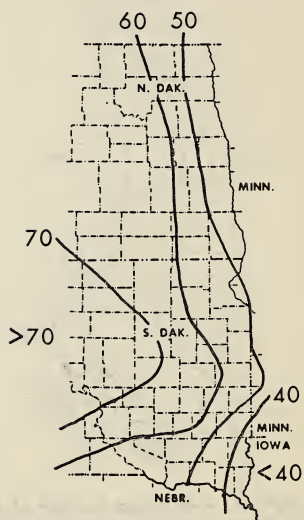
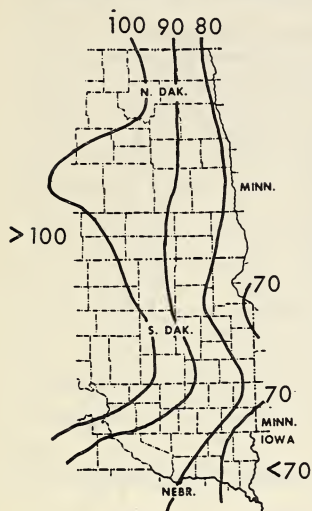
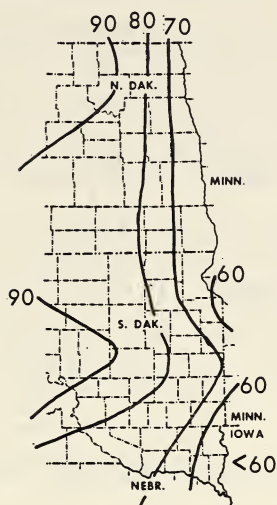


FIGURE 12.—Minimum number of drought-days to be expected for 5-inch base amount of soil-moisture storage capacity at probabilities of 1, 2, 3, and 5 out of 10 years in eastern North Dakota and South Dakota from May through September.

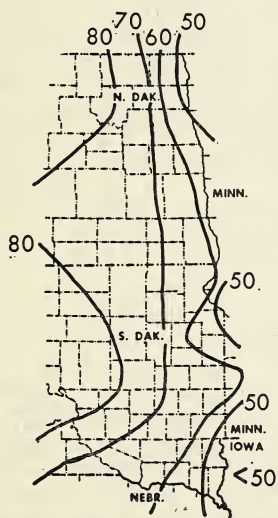
1 OUT OF 10 YEARS



2 OUT OF 10 YEARS



3 OUT OF 10 YEARS



5 OUT OF 10 YEARS

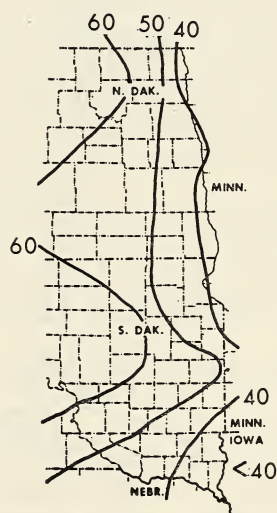
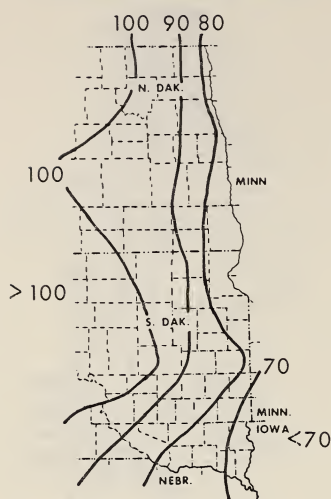
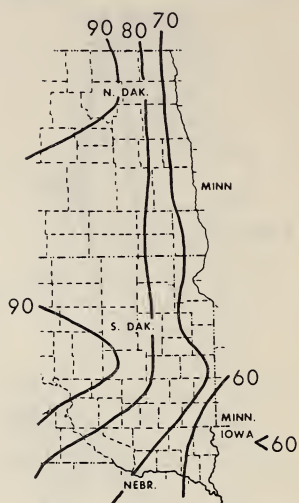


FIGURE 13.—Minimum number of drought-days to be expected for 7-inch base amount of soil-moisture storage capacity at probabilities of 1, 2, 3, and 5 out of 10 years in eastern North Dakota and South Dakota from May through September.

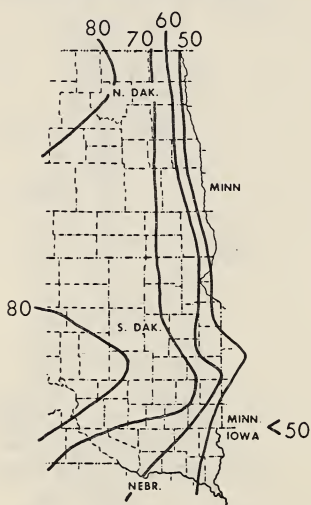
1 OUT OF 10 YEARS



2 OUT OF 10 YEARS



3 OUT OF 10 YEARS



5 OUT OF 10 YEARS

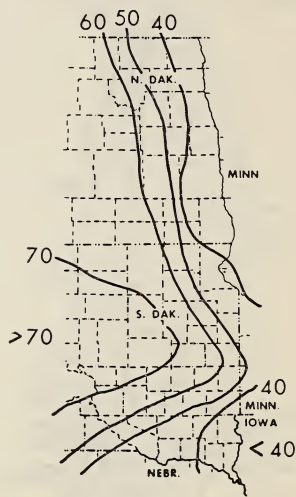


FIGURE 14.—Minimum number of drought-days to be expected for 9-inch base amount of soil-moisture storage capacity at probabilities of 1, 2, 3, and 5 out of 10 years in eastern North Dakota and South Dakota from May through September.

Monthly Drought-Days

The information obtained for seasonal drought-days is too general to be applied to specific crops. However, the same procedure can be applied to monthly drought-days. In table 2 is shown the minimum number of drought-days to be expected for five base amounts at four probabilities in seven areas. For example, in area A in May for a 5-inch base amount at a probability of 1 out of 10 years, 28 drought-days may be expected. However, under the same conditions in area G only 18 drought-days may be expected.

One common error is often made by those unfamiliar with the rules of probability calculus. One cannot add the number of drought-days for each month at any one base amount and probability and expect to obtain the number of drought-days for the season, as shown in figures 10-14. Such a summation would be an overestimate of the seasonal total, because the drought-days from one month to the next are only *closely*, not *perfectly*, correlated. Without detailed studies no exact procedure can be given for such an addition.

Minimum Irrigation Water Required To Offset Drought

The amount of supplemental water needed to offset the effects of drought can be calculated by using the data in tables 1 and 2. Multiply the number of drought-days for a given area at a certain base amount and probability (table 2) by the corresponding evapotranspiration value (table 1). The product will be the inches of water required to offset the drought for the specified conditions. Table 3 shows these values for 9, 7, and 5 out of 10 years. The figures are based on the supposition that all the water applied goes directly into the soil and is useful to the plants. This is an error for which allowance must be made depending on the type and conditions of irrigation.

For example, in table 2 for area A in May with a 5-inch base amount at a probability of 1 out of 10 years, the number of drought-days is 28. In table 1 the evapotranspiration value is 0.12 inch per day. The product of these two values is 3.36 inches, which is the minimum amount of water required to eliminate the drought in 9 out of 10 years (table 3).

If the rooting depth of corn, for example, is 2 feet and the soil-moisture storage capacity is $1\frac{1}{2}$ inches per foot of soil, the figures for a 3-inch base amount would be applicable.

The length of time to wait between irrigations can be determined. For example, if 3 inches of water are applied to the root zone in July in South Dakota, the rate of evapotranspiration would be 0.17 inch per day (table 1). Dividing 3 by 0.17 shows that in 18 days all the applied water would be gone.

Seasonal Excess Moisture

A series of frequency distributions were made of seasonal excess moisture similar to those of seasonal drought-days. Figures 15-19 show the excess moisture to be expected for five base amounts at four probabilities.

TABLE 2.—*Minimum number of drought-days to be expected for five base amounts of soil-moisture storage capacity at four probabilities in seven areas of eastern North Dakota and South Dakota from May through September*

PROBABILITY: 1 OUT OF 10 YEARS

Area ¹ and base amount (inches)	May	June	July	August	September
A:					
1-----	29	25	27	28	30
3-----	28	22	26	28	30
5-----	28	22	26	28	29
7-----	28	22	26	28	29
9-----	28	22	26	28	28
B:					
1-----	30	21	27	27	27
3-----	27	20	25	26	27
5-----	27	20	24	26	27
7-----	27	20	24	25	27
9-----	27	20	24	25	27
C:					
1-----	27	22	28	29	27
3-----	23	21	27	28	27
5-----	20	20	26	28	26
7-----	20	20	26	27	26
9-----	20	20	26	27	26
D:					
1-----	31	23	31	31	30
3-----	28	21	31	31	30
5-----	27	21	31	31	30
7-----	27	21	31	31	30
9-----	27	21	31	31	30
E:					
1-----	25	22	28	28	27
3-----	20	20	27	28	26
5-----	20	19	27	26	24
7-----	20	19	27	26	24
9-----	20	19	27	26	24
F:					
1-----	24	24	28	31	30
3-----	22	23	26	31	30
5-----	22	22	26	31	30
7-----	22	22	23	30	30
9-----	22	22	23	30	30
G:					
1-----	22	22	28	25	26
3-----	19	19	26	23	24
5-----	18	17	24	23	24
7-----	18	16	23	22	24
9-----	18	16	22	22	24

¹ A, B, and C in North Dakota and other areas in South Dakota (see fig. 1).

TABLE 2.—*Minimum number of drought-days to be expected for five base amounts of soil-moisture storage capacity at four probabilities in seven areas of eastern North Dakota and South Dakota from May through September—Continued*

PROBABILITY: 2 OUT OF 10 YEARS

Area ¹ and base amount (inches)	May	June	July	August	September
A:					
1.....	26	21	24	25	26
3.....	23	18	22	25	25
5.....	22	17	22	24	24
7.....	22	17	22	24	24
9.....	22	17	22	24	23
B:					
1.....	26	19	24	24	25
3.....	23	16	21	23	25
5.....	22	16	20	22	25
7.....	22	16	19	21	24
9.....	22	16	19	21	24
C:					
1.....	23	20	25	26	24
3.....	19	16	23	24	23
5.....	16	15	21	24	23
7.....	16	15	20	23	23
9.....	16	15	20	22	23
D:					
1.....	26	20	28	29	28
3.....	23	17	26	28	27
5.....	22	16	26	28	27
7.....	22	16	26	27	26
9.....	22	16	26	26	26
E:					
1.....	22	19	26	25	24
3.....	17	16	23	23	21
5.....	16	14	22	22	20
7.....	16	14	22	22	20
9.....	16	14	22	22	20
F:					
1.....	21	20	26	28	26
3.....	19	18	24	27	25
5.....	18	17	22	27	25
7.....	18	17	20	26	25
9.....	18	17	20	26	25
G:					
1.....	19	18	26	22	22
3.....	14	14	22	20	20
5.....	12	11	20	19	19
7.....	12	10	19	18	19
9.....	12	10	18	18	19

¹ A, B, and C in North Dakota and other areas in South Dakota (see fig. 1).

TABLE 2.—*Minimum number of drought-days to be expected for five base amounts of soil-moisture storage capacity at four probabilities in seven areas of eastern North Dakota and South Dakota from May through September—Continued*

PROBABILITY: 3 OUT OF 10 YEARS

Area ¹ and base amount (inches)	May	June	July	August	September
A:					
1-----	23	18	22	23	22
3-----	20	15	19	22	21
5-----	18	14	18	22	20
7-----	18	14	18	21	20
9-----	18	14	18	20	19
B:					
1-----	23	17	22	22	23
3-----	20	13	18	21	22
5-----	18	13	17	20	22
7-----	18	13	16	18	21
9-----	18	13	16	18	21
C:					
1-----	21	17	22	23	22
3-----	15	13	20	21	20
5-----	13	10	16	21	19
7-----	13	10	15	20	19
9-----	13	10	15	19	19
D:					
1-----	23	18	25	25	24
3-----	20	13	23	25	24
5-----	19	13	22	24	24
7-----	19	13	22	24	23
9-----	19	13	22	23	22
E:					
1-----	19	17	24	23	21
3-----	14	13	20	21	18
5-----	13	11	18	19	16
7-----	13	11	18	18	16
9-----	13	11	18	18	16
F:					
1-----	19	18	24	25	24
3-----	17	14	22	24	22
5-----	16	13	20	24	21
7-----	16	13	18	23	21
9-----	16	13	18	22	21
G:					
1-----	16	16	24	20	20
3-----	11	10	20	18	17
5-----	9	7	18	17	16
7-----	9	5	16	16	16
9-----	9	5	15	16	15

¹ A, B, and C in North Dakota and other areas in South Dakota (see fig. 1).

TABLE 2.—*Minimum number of drought-days to be expected for five base amounts of soil-moisture storage capacity at four probabilities in seven areas of eastern North Dakota and South Dakota from May through September—Continued*

PROBABILITY: 5 OUT OF 10 YEARS

Area ¹ and base amount (inches)	May	June	July	August	September
A:					
1-----	19	14	19	19	18
3-----	14	10	15	17	15
5-----	12	8	13	16	14
7-----	12	8	12	15	13
9-----	12	8	12	15	13
B:					
1-----	18	14	19	19	18
3-----	13	9	14	17	18
5-----	12	8	11	16	16
7-----	12	8	10	14	16
9-----	12	8	10	14	15
C:					
1-----	17	14	19	19	18
3-----	10	8	14	16	14
5-----	8	4	10	16	13
7-----	8	4	8	14	13
9-----	8	4	8	14	13
D:					
1-----	18	14	22	20	20
3-----	14	8	18	20	19
5-----	13	7	15	19	18
7-----	13	7	15	18	18
9-----	13	7	15	17	17
E:					
1-----	16	13	21	19	17
3-----	10	8	14	15	12
5-----	8	5	12	14	11
7-----	8	5	11	13	10
9-----	8	5	11	13	10
F:					
1-----	16	14	22	21	20
3-----	12	8	18	19	16
5-----	11	6	16	19	15
7-----	11	6	15	18	15
9-----	11	6	15	17	15
G:					
1-----	13	12	21	17	16
3-----	5	4	15	14	12
5-----	3	0	13	13	10
7-----	3	0	10	12	10
9-----	3	0	9	11	9

¹ A, B, and C in North Dakota and other areas in South Dakota (see fig. 1).

TABLE 3.—*Minimum irrigation water required to offset drought for five base amounts of soil-moisture storage capacity at three probabilities in seven areas of eastern North Dakota and South Dakota from May through September*

PROBABILITY: 9 OUT OF 10 YEARS

Area ¹ and base amount (inches)	May	June	July	August	September
A:	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>
1-----	3.48	3.75	4.32	3.64	2.70
3-----	3.36	3.30	4.16	3.64	2.70
5-----	3.36	3.30	4.16	3.64	2.61
7-----	3.36	3.30	4.16	3.64	2.61
9-----	3.36	3.30	4.16	3.64	2.52
B:					
1-----	3.60	3.15	4.32	3.51	2.43
3-----	3.24	3.00	4.00	3.38	2.43
5-----	3.24	3.00	3.84	3.38	2.43
7-----	3.24	3.00	3.84	3.25	2.43
9-----	3.24	3.00	3.84	3.25	2.43
C:					
1-----	3.24	3.30	4.48	3.77	2.43
3-----	2.76	3.15	4.32	3.64	2.43
5-----	2.40	3.00	4.16	3.64	2.34
7-----	2.40	3.00	4.16	3.51	2.34
9-----	2.40	3.00	4.16	3.51	2.34
D:					
1-----	3.72	3.68	5.27	4.34	3.00
3-----	3.36	3.36	5.27	4.34	3.00
5-----	3.24	3.36	5.27	4.34	3.00
7-----	3.24	3.36	5.27	4.34	3.00
9-----	3.24	3.36	5.27	4.34	3.00
E:					
1-----	3.00	3.52	4.76	3.92	2.70
3-----	2.40	3.20	4.59	3.92	2.60
5-----	2.40	3.04	4.59	3.64	2.40
7-----	2.40	3.04	4.59	3.64	2.40
9-----	2.40	3.04	4.59	3.64	2.40
F:					
1-----	2.88	3.84	4.76	4.34	3.00
3-----	2.64	3.68	4.42	4.34	3.00
5-----	2.64	3.52	4.42	4.34	3.00
7-----	2.64	3.52	3.91	4.20	3.00
9-----	2.64	3.52	3.91	4.20	3.00
G:					
1-----	2.64	3.52	4.76	3.50	2.60
3-----	2.28	3.04	4.42	3.22	2.40
5-----	2.16	2.72	4.08	3.22	2.40
7-----	2.16	2.56	3.91	3.08	2.40
9-----	2.16	2.56	3.74	3.08	2.40

¹ A, B, and C in North Dakota and other areas in South Dakota (see fig. 1).

TABLE 3.—*Minimum irrigation water required to offset drought for five base amounts of soil-moisture storage capacity at three probabilities in seven areas of eastern North Dakota and South Dakota from May through September—Continued*

PROBABILITY: 7 OUT OF 10 YEARS

Area ¹ and base amount (inches)	May	June	July	August	September
A:	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>
1-----	2.76	2.70	3.52	2.99	1.98
3-----	2.40	2.25	3.04	2.86	1.89
5-----	2.16	2.10	2.88	2.86	1.80
7-----	2.16	2.10	2.88	2.73	1.80
9-----	2.16	2.10	2.88	2.60	1.71
B:					
1-----	2.76	2.55	3.52	2.86	2.07
3-----	2.40	1.95	2.88	2.73	1.98
5-----	2.16	1.95	2.72	2.60	1.98
7-----	2.16	1.95	2.56	2.34	1.89
9-----	2.16	1.95	2.56	2.34	1.89
C:					
1-----	2.52	2.55	3.52	2.99	1.98
3-----	1.80	1.95	3.20	2.73	1.80
5-----	1.56	1.50	2.56	2.73	1.71
7-----	1.56	1.50	2.40	2.60	1.71
9-----	1.56	1.50	2.40	2.47	1.71
D:					
1-----	2.76	2.88	4.25	3.50	2.40
3-----	2.40	2.08	3.91	3.50	2.40
5-----	2.28	2.08	3.74	3.36	2.40
7-----	2.28	2.08	3.74	3.36	2.30
9-----	2.28	2.08	3.74	3.22	2.20
E:					
1-----	2.28	2.72	4.08	3.22	2.10
3-----	1.68	2.08	3.40	2.94	1.80
5-----	1.56	1.76	3.06	2.66	1.60
7-----	1.56	1.76	3.06	2.52	1.60
9-----	1.56	1.76	3.06	2.52	1.60
F:					
1-----	2.28	2.88	4.08	3.50	2.40
3-----	2.04	2.24	3.74	3.36	2.20
5-----	1.92	2.08	3.40	3.36	2.10
7-----	1.92	2.08	3.06	3.22	2.10
9-----	1.92	2.08	3.06	3.08	2.10
G:					
1-----	1.92	2.56	4.08	2.80	2.00
3-----	1.32	1.60	3.40	2.52	1.70
5-----	1.08	1.12	3.06	2.38	1.60
7-----	1.08	.80	2.72	2.24	1.60
9-----	1.08	.80	2.55	2.24	1.50

¹ A, B, and C in North Dakota and other areas in South Dakota (see fig. 1).

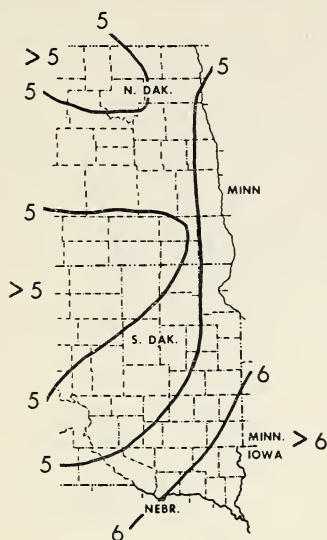
TABLE 3.—*Minimum irrigation water required to offset drought for five base amounts of soil-moisture storage capacity at three probabilities in seven areas of eastern North Dakota and South Dakota from May through September—Continued*

PROBABILITY: 5 OUT OF 10 YEARS

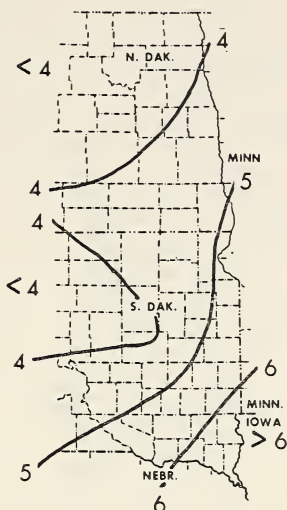
Area ¹ and base amount (inches)	May	June	July	August	September
A:	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>	<i>Inches</i>
1-----	2. 28	2. 10	3. 04	2. 47	1. 62
3-----	1. 68	1. 50	2. 40	2. 21	1. 35
5-----	1. 44	1. 20	2. 08	2. 08	1. 26
7-----	1. 44	1. 20	1. 92	1. 95	1. 17
9-----	1. 44	1. 20	1. 92	1. 95	1. 17
B:					
1-----	2. 16	2. 10	3. 04	2. 47	1. 62
3-----	1. 56	1. 35	2. 24	2. 21	1. 62
5-----	1. 44	1. 20	1. 76	2. 08	1. 44
7-----	1. 44	1. 20	1. 60	1. 82	1. 44
9-----	1. 44	1. 20	1. 60	1. 82	1. 35
C:					
1-----	2. 04	2. 10	3. 04	2. 47	1. 62
3-----	1. 20	1. 20	2. 24	2. 08	1. 26
5-----	. 96	. 60	1. 60	2. 08	1. 17
7-----	. 96	. 60	1. 28	1. 82	1. 17
9-----	. 96	. 60	1. 28	1. 82	1. 17
D:					
1-----	2. 16	2. 24	3. 74	2. 80	2. 00
3-----	1. 68	1. 28	3. 06	2. 80	1. 90
5-----	1. 56	1. 12	2. 55	2. 66	1. 80
7-----	1. 56	1. 12	2. 55	2. 52	1. 80
9-----	1. 56	1. 12	2. 55	2. 38	1. 70
E:					
1-----	1. 92	2. 08	3. 57	2. 66	1. 70
3-----	1. 20	1. 28	2. 38	2. 10	1. 20
5-----	. 96	. 80	2. 04	1. 96	1. 10
7-----	. 96	. 80	1. 87	1. 82	1. 00
9-----	. 96	. 80	1. 87	1. 82	1. 00
F:					
1-----	1. 92	2. 24	3. 74	2. 94	2. 00
3-----	1. 44	1. 28	3. 06	2. 66	1. 60
5-----	1. 32	. 96	2. 72	2. 66	1. 50
7-----	1. 32	. 96	2. 55	2. 52	1. 50
9-----	1. 32	. 96	2. 55	2. 38	1. 50
G:					
1-----	1. 56	1. 92	3. 57	2. 38	1. 60
3-----	. 60	. 64	2. 55	1. 96	1. 20
5-----	. 36	0	2. 21	1. 82	1. 00
7-----	. 36	0	1. 70	1. 68	1. 00
9-----	. 36	0	1. 53	1. 54	. 90

¹ A, B, and C in North Dakota and other areas in South Dakota (see fig. 1).

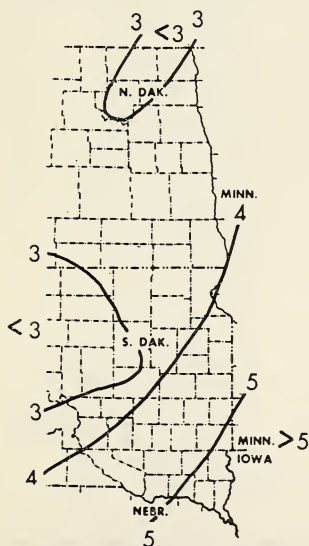
1 OUT OF 10 YEARS



2 OUT OF 10 YEARS



3 OUT OF 10 YEARS



5 OUT OF 10 YEARS

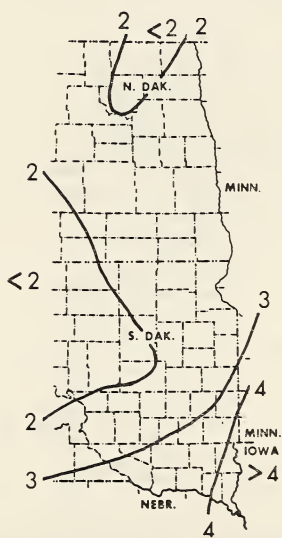
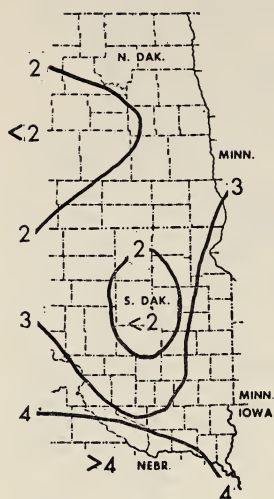
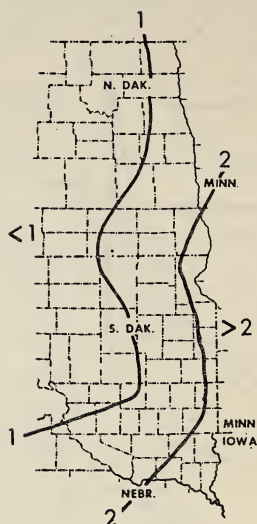


FIGURE 15.—Minimum excess moisture (inches) to be expected for 1-inch base amount of soil-moisture storage capacity at probabilities of 1, 2, 3, and 5 out of 10 years in eastern North Dakota and South Dakota from May through September.

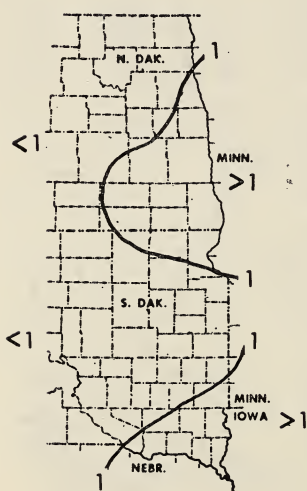
1 OUT OF 10 YEARS



2 OUT OF 10 YEARS



3 OUT OF 10 YEARS



5 OUT OF 10 YEARS

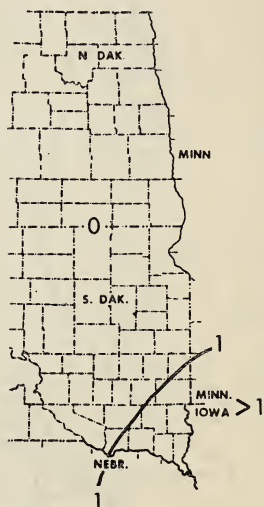
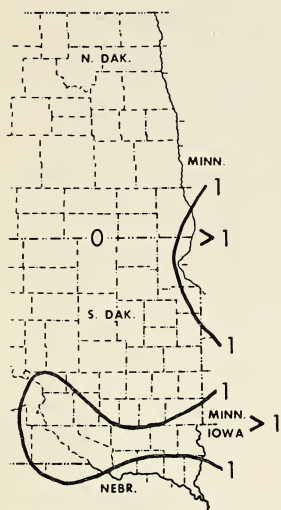
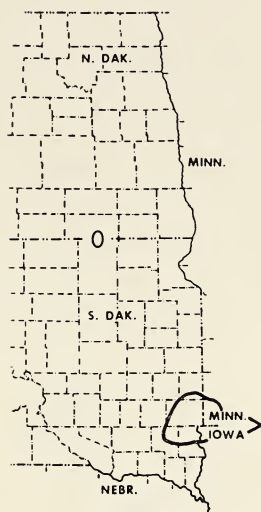


FIGURE 16.—Minimum excess moisture (inches) to be expected for 3-inch base amount of soil-moisture storage capacity at probabilities of 1, 2, 3, and 5 out of 10 years in eastern North Dakota and South Dakota from May through September.

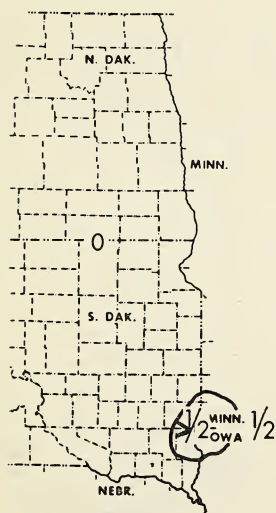
1 OUT OF 10 YEARS



2 OUT OF 10 YEARS



3 OUT OF 10 YEARS



5 OUT OF 10 YEARS

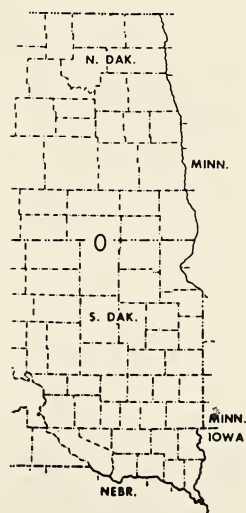
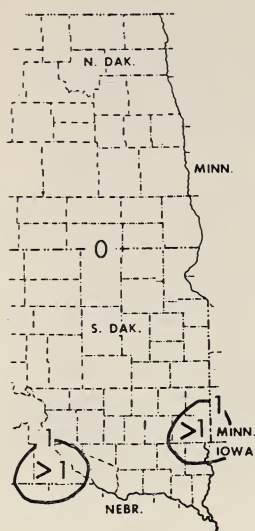
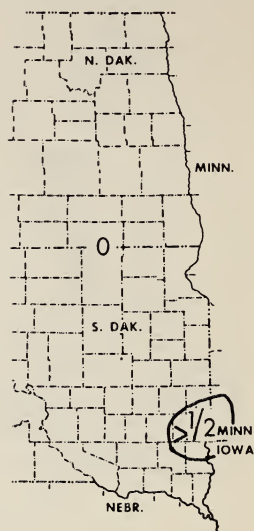


FIGURE 17.—Minimum excess moisture (inches) to be expected for 5-inch base amount of soil-moisture storage capacity at probabilities of 1, 2, 3, and 5 out of 10 years in eastern North Dakota and South Dakota from May through September.

1 OUT OF 10 YEARS



2 OUT OF 10 YEARS



3 OUT OF 10 YEARS



5 OUT OF 10 YEARS

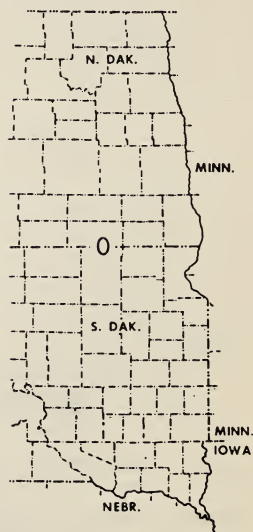
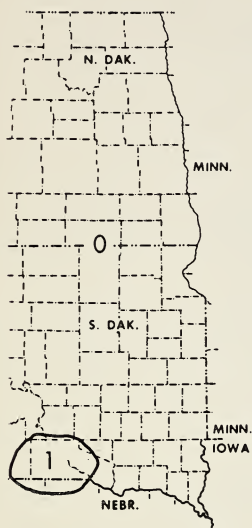
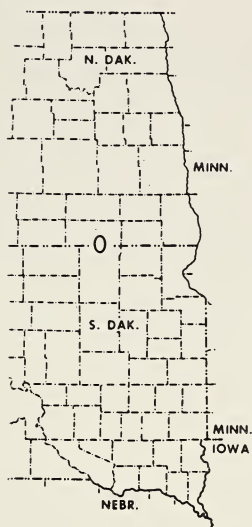


FIGURE 18.—Minimum excess moisture (inches) to be expected for 7-inch base amount of soil-moisture storage capacity at probabilities of 1, 2, 3, and 5 out of 10 years in eastern North Dakota and South Dakota from May through September.

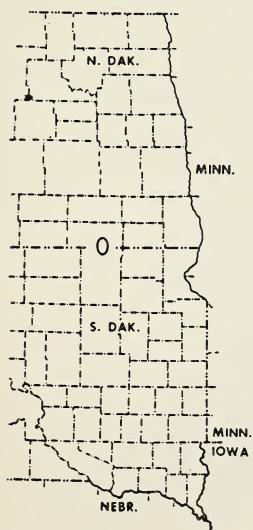
1 OUT OF 10 YEARS



2 OUT OF 10 YEARS



3 OUT OF 10 YEARS



5 OUT OF 10 YEARS

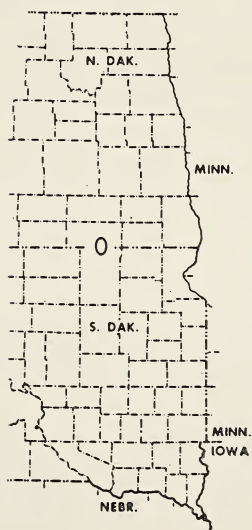


FIGURE 19.—Minimum excess moisture (inches) to be expected for 9-inch base amount of soil-moisture storage capacity at probabilities of 1, 2, 3, and 5 out of 10 years in eastern North Dakota and South Dakota from May through September.

Very little excess moisture was recorded for a 7- or 9-inch base amount. However, at the lower base amounts some excess did occur. Thus on a soil with only a 1-inch base amount of soil-moisture storage capacity at a probability of 5 out of 10 years, or every other year, for the 5-month season near the eastern boundary of South Dakota, there would be about 70 drought-days (fig. 10) but also more than 4 inches of excess moisture (fig. 15).

CONCLUSIONS

This study has shown that agricultural drought and excess soil moisture can be predicted under specified conditions of soil-moisture availability, evapotranspiration, and precipitation in eastern North Dakota and South Dakota.

In proceeding from east to west in eastern North Dakota and South Dakota the number of drought-days from May through September increased and the excess moisture decreased. The fewest number of drought-days was about 40. These findings point out the necessity of conserving the water resources in this area.

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